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MANNED EVALUATION OF THE MK-15 UBA (UNDERWATER  
BREATHING APPARATUS) CANIS..(U) NAVY EXPERIMENTAL  
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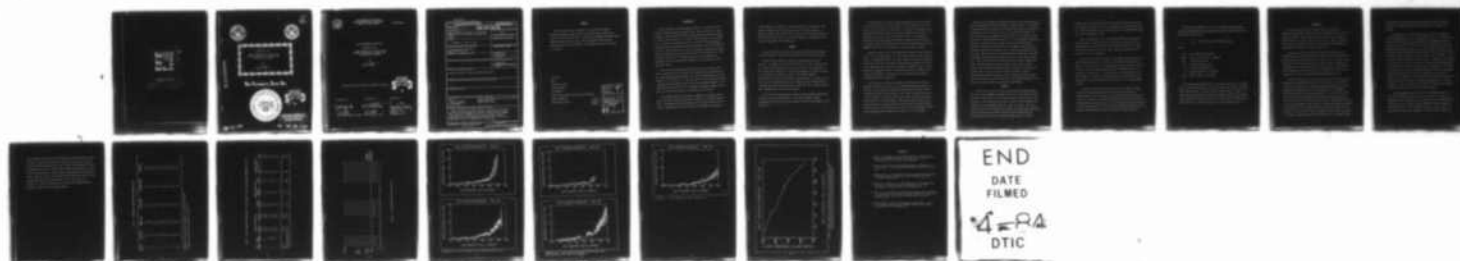
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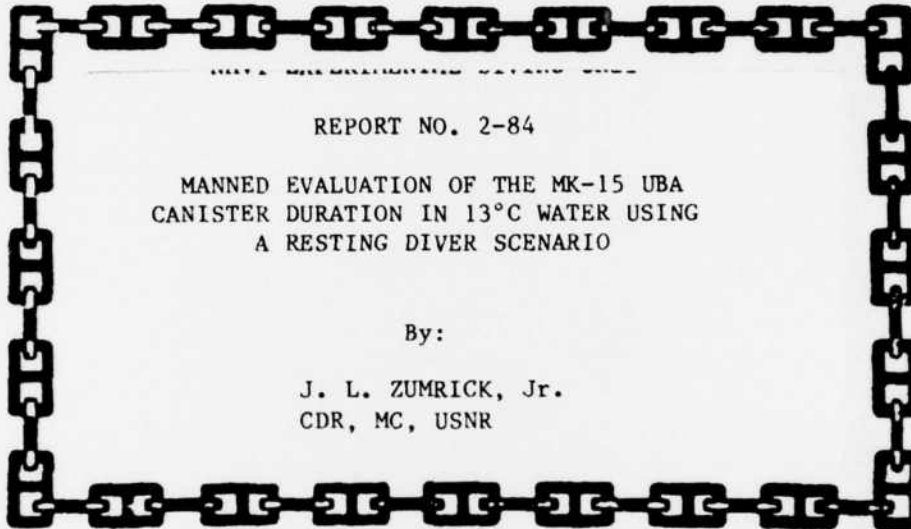
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REPORT NO. 2-84

MANNED EVALUATION OF THE MK-15 UBA  
CANISTER DURATION IN 13°C WATER USING  
A RESTING DIVER SCENARIO

By:

J. L. ZUMRICK, Jr.  
CDR, MC, USNR

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## NAVY EXPERIMENTAL DIVING UNIT



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# ABSTRACT

The CO<sub>2</sub> absorbent canister duration of the MK-15 closed-circuit Underwater Breathing Apparatus (UBA) was evaluated using a resting diver scenario in 13°C water at 65 FSW. The Passive Diver Thermal Protection System (PDTPS) was worn during the study. Results demonstrate that the safe operational limit of the MK-15 UBA for a diver mainly at rest in 13°C water is 321 minutes.

## Key Words:

MK-15

Closed-Circuit UBA

Canister Duration

CO<sub>2</sub> Absorbent

Passive Diver Thermal Protection System (PDTPS)

Oxygen Consumption

NEDU Study No. 83/42



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## INTRODUCTION

The MK-15 Underwater Breathing Apparatus (UBA) is a closed-circuit UBA designed to support extended diving operations of up to six hours. In normal operation, it automatically maintains the inspired partial pressure of oxygen at a pre-set level, usually  $0.7 \pm 0.05$  ATM, by adding oxygen to the breathing loop to replace that consumed by the diver. The diver's exhaled gas passes through a carbon dioxide absorbent canister which extracts the  $\text{CO}_2$  produced by the diver. Except during ascent, the breathing gases are completely contained within the breathing loop and no losses occur to the surrounding water. When gas leaks from the MK-15 are minimal, the duration of the apparatus is determined either by the oxygen bottle capacity or the duration of the  $\text{CO}_2$  absorbent canister.

Previous studies have demonstrated that the operational limit of the MK-15 is determined not by the oxygen bottle capacity but by the duration of the carbon dioxide absorbent canister (1). This study demonstrated a canister duration of 117.5 minutes in  $2^\circ\text{C}$  ( $35.6^\circ\text{F}$ ) and  $13.4^\circ\text{C}$  ( $56.1^\circ\text{F}$ ) water when using a standard canister testing protocol consisting of alternating periods of six minutes work and 4 minutes rest on an underwater pedal-mode ergometer set at a work rate of 50 watts resulting in a mean  $\dot{V}\text{CO}_2$  of 1.5-2.0 l/min.

The standard canister testing protocol simulates the maximum exercise that a diver can reasonably be expected to sustain for a prolonged period of time. An apparatus which provides adequate carbon dioxide removal over its required time duration using this protocol can reasonably be expected to

provide adequate life support for a diverse variety of dive scenarios. This procedure, however, may not adequately describe a UBA's performance in a limited and specific application. UBAs can be used in diving scenarios where divers may be mainly at rest, this study was undertaken to demonstrate MK-15 canister duration under these conditions.

#### METHODS

All dive subjects were military trained divers familiar with the operation of the MK-15 UBA. Their physical characteristics are given in Table 1.

All dives were conducted in the OSF wet chamber chilled to 13.0°C (56.0°F). The chamber was pressurized to 60 FSW on air with a platform in the wet chamber 5 feet below the water level, resulting in a diver depth of 65 FSW. Exercise was provided by two pedal-mode ergometers (2) which were placed on the platform in a horizontal attitude. This allowed two MK-15 diver-subjects to exercise simultaneously, thereby doubling the number of runs which could be accomplished each day. A standby diver with communications to the surface was ready to assist the divers during all tests. The MK-15 divers had no communications other than hand signals.

Each diver wore the Passive Diver Thermal Protection System (PDTPS) which consisted of full long john underwear, wool socks, Thinsulate thermal undergarment with hood, dry suit outer garment with gloves, and weights at the midline (6).



The initial UBA set up and all canister changes were done on the surface. Prior to each dive day, three MK-15 UBA's were set to maintain  $PO_2$  at  $0.70 \pm 0.05$  ATA. Air was used as the diluent gas. To prevent dive termination due to an exhausted diluent gas supply, each UBA was provided with an umbilical air supply for diluent gas in place of the diluent bottle. A fully-charged, rechargeable nickel-cadium battery was used for each dive, and the canisters were freshly packed and weighed using the same batch of High Performance (H.P.) SODASORB (W. R. Grant & Co.) throughout all canister duration studies.

Canister effluent  $CO_2$  and  $O_2$  gas samples were obtained by small diameter (.032 in i.d.) capillary sample lines with sampling rates of 200 to 500 cc/min (STPD). A micrometering valve at the sample origin for flow control allowed a delay time of less than two seconds and provided rapid response to variations in gas composition without significant mixing in the sample line (3). The gas samples were analyzed by either a Perkin Elmer MGA 1100 or a Chemetron Model 7401 mass spectrometer. An accuracy of  $\pm 0.01\%$  was obtained by frequent calibrations during the experiment.

The oxygen bottle pressure was measured by a Validyne DP 15 Pressure Transducer equipped with a 3000 psig  $\pm 1\%$  diaphragm which was mounted on the MK-15 UBA. This transducer was calibrated from 0-2500 psi against a Mensor 11600 digital pressure gauge (2500 psi  $\pm 0.04\%$ ) before and after each study. A linear regression of Validyne voltage versus digital pressure gauge reading was calculated by a HP-1000 computer. The Validyne output voltage was then directly converted to pounds per square inch each time the computer sampled. After each run, a plot of oxygen bottle pressure versus time was made, and the oxygen consumption was estimated from this plot, as will be described.

Once all the equipment was checked and calibrated, the divers entered the water and performed the exercise sequence as shown in Figure 1. This exercise sequence was designed to simulate missions where short periods of exercise are interspersed with long periods of rest. During the exercise periods, the divers worked against an ergometer setting of 50 watts, at a rate of 55 rpm. The actual work load performed by the diver, due to the combined resistance of the water and thermal protection garment, was 25-50 watts greater than indicated. During the rest periods, the divers engaged in game tasks which kept them occupied and essentially at rest. The dives were terminated when either the canister effluent  $\text{CO}_2$  exceeded 2.0% Surface Equivalent Value (SEV) (15.8 mmHg) at any time during the work cycles for at least 1 minute during rest, or when 3% SEV value (22.8 mmHg) was reached at any point during the study. These termination points were chosen to ensure that a definite canister end point could be established that was unaffected by the diver's activity level. These  $\text{CO}_2$  levels are greater than those to which an operational diver should be exposed, and are acceptable only under rigidly controlled circumstances where they provide a clearly defined end point to the study from which an operational duration can be determined.

#### RESULTS

A total of five canister durations were successfully completed during this study. Water temperature averaged  $12.9 \pm 0.2^\circ\text{C}$ . The canister effluent  $\text{CO}_2$  versus time charts for the five tests are found in Figures 2A-2E. Close inspection of these showed short periods of rising  $\text{CO}_2$  which represents the exercise periods interspersed within the longer rest periods. After five hours, when the six minute exercise, four minute rest sequence was continuous, canister effluent  $\text{CO}_2$  rose sharply during work and declined during the intervening rest period forming a jagged sinusoidal pattern. Canister

duration times were determined by digitizing those mean peak  $\text{CO}_2$  values and then obtaining the best data fit using a polynomial regression equation (Table 2). canister duration was taken as the time where the regression line crossed the 0.5% SEV (3.8 mmHg)  $\text{CO}_2$  value.

Table 2 summarizes the overall diver oxygen consumption ( $\dot{V}_{\text{O}_2}$ ) during the study, the oxygen consumption during rest and exercise, pre and post dive canister weights, and the time taken for the canister effluent  $\text{CO}_2$  to reach 0.5% SEV and 1.0% SEV for each dive. Mean canister breakthrough time was calculated to be  $321 \pm 25$  minutes.

During two of the dives, the divers were replaced during the rest cycle and the dive continued with a new diver. These changes are represented in Table 2 as Diver #3/8 and 5/10. Both divers were replaced because of fatigue and cold. The nickel-cadmium batteries used to power the MK-15 had to be changed on all five tests. The average duration of the battery was 4 hr 50 min  $\pm$  29 minutes. During long diving operations, an alkaline battery with significantly longer duration would be used rather than the nickel-cadmium battery.

An example of oxygen bottle pressure versus time is shown in Figure 3. Two rates of bottle pressure decline are shown; a more rapid decline associated with the exercise periods, and a gradual decline associated with the long rest periods. In addition, the oxygen decline during rest appears to be biphasic with a slightly greater rate of decline during the latter portion of the long rest periods. All divers reported feeling increasingly cold and shivering during this period which was relieved on beginning exercise.

Overall, oxygen consumption for the entire study period was calculated using the following formula which assumes no gas leaks from the UBA other than the known gas sample rates:

$$\dot{V}_{O_2} = (\Delta P / \Delta T) \cdot (V_B / 14.7) \cdot [273 / (T + 273)] - V_S \cdot F_{O_{2S}}$$

where:

- $\dot{V}_{O_2}$  =  $O_2$  consumption (l/min STPD)
- $\Delta P / \Delta T$  = Slope of  $O_2$  pressure plot (psi/min)
- $V_B$  =  $O_2$  bottle volume (l)
- 14.7 = psi/ATA conversion factor
- $T$  =  $O_2$  bottle temperature ( $^{\circ}C$ )
- $V_S$  = UBA gas sample rate (.250 SLPM)
- $F_{O_{2S}}$  = Oxygen fraction in gas sample

The average oxygen consumption rate during exercise was  $2.24 \pm .15$  l/min, and  $.64 \pm .09$  l/min during rest. The overall rate of diver oxygen consumption ranged from 0.8 l/min to 1.06 l/min with an average of  $0.95 \pm .14$  l/min. Gas leaks which occurred during the study had a minimum influence on these values since the partial pressure of  $O_2$  in the air diluent used at 65 FSW to make up volume was 0.63 atm and nearly identical to the MK-15 oxygen set point.

## DISCUSSION

In practice, canister duration times exhibit wide variability. Unpublished observations during both manned and unmanned testing at NEDU show that small changes in CO<sub>2</sub> production rates may result in large changes in canister duration. Moreover, additional factors such as ambient temperature, flow rate of gas through the canister, canister packing with SODASORB, and breathing patterns may affect canister duration times.

A previous study, which evaluated MK-15 canister durations using a standard canister testing protocol used at NEDU, reported canister durations which averaged 47% less than those found in this study (1). However, in that study, due to the greater level of diver exertion, oxygen consumption and consequently the CO<sub>2</sub> production rates were 42% greater than in this study. Thus, variations in the CO<sub>2</sub> production rate would appear to account for the differences in canister durations measured during the two studies.

During the previous MK-15 study, canister duration in 2°C water was not significantly different from that found in 13.4°C water. In the previous study, divers exercised more and had similar oxygen consumptions at the two temperatures, indicating that cold stress did not result in significant shivering and therefore, additional CO<sub>2</sub> production. In this study, divers reported being cold and experiencing intermittent shivering particularly during the latter portion of the long rest periods. These subjective feelings of cold were supported by a slight increase in oxygen consumption as indicated by the biphasic nature of oxygen bottle pressure declines during the latter portion of the rest periods. Canister durations in colder water are expected to be shorter using this resting diver scenario due to the increased oxygen

consumption from shivering. Therefore, additional testing is required to determine MK-15 canister duration in 2°C water using the resting diver scenario.

The designation of a carbon dioxide limit of 0.5% SEV to establish canister breakthrough time is not a physiological limit, but a practical one based on the CO<sub>2</sub> effluent curve and the need for a standardized endpoint. Inspired CO<sub>2</sub> levels of up to 2% SEV are safe to breathe without significant detrimental physiological effects (4). As can be seen in the figures, once canister effluent CO<sub>2</sub> reaches 0.5% SEV, rapid increases in canister effluent CO<sub>2</sub> can be expected thereafter. The mean time for canister effluent to reach 0.5% SEV was  $321 \pm 25$  minutes, while it took  $368 \pm 31$  minutes to reach 1% SEV. If the subjects in this study are taken to represent the normal population of divers who will use the MK-15, a minimum time of 306 minutes to reach 1% SEV can be expected for 97.5% of the general population (mean minus two standard deviations) and 335 minutes for 82% of the population of MK-15 divers. Therefore, it is reasonable to use the value of 321 minutes, the mean time to reach 0.5% SEV as an indication of canister breakthrough since a canister effluent of 1% SEV carbon dioxide is not likely to occur over this slightly increased interval, and a 2% level is extremely unlikely.

It must be emphasized that the value of 321 minutes applies only to a diver who is predominantly resting in 13°C (55°F) water. It must also be emphasized that any operational factor which results in an increased diver CO<sub>2</sub> production (such as a decrease in diver thermal protection, an increase in diver exercise level due to as equipment failure, etc.) will result in a significantly shorter canister duration. This means that at present the

321 min duration time will have little operational application until a method is found to do real time integration of diver exercise rate and relate this directly to canister duration time. Since the above operational factors must be considered likely, it is advisable that equipment modifications to increase canister duration be made. The goal sought by such modifications should be to produce a canister duration to meet mission requirements when tested using the standard NEDU canister duration testing procedure. When this goal is achieved, it is likely that missions will be limited by thermal protection constraints rather than his breathing apparatus.

TABLE 1. INDIVIDUAL DIVER PHYSICAL CHARACTERISTICS

<u>Diver #</u>	<u>Age (Yrs)</u>	<u>Height (cm)</u>	<u>Weight (kg)</u>	<u>Skinfold (mm)</u>	<u>% Body Fat</u>
1	38	173	75	70	36.5
2	34	178	92	60	34.5
3	26	173	68	19	20.5
4	23	163	65	49	32.1
5	19	178	64	26	24.4
6	42	185	95	56	33.7
7	34	178	76	58	34.1
8	26	180	89	61	35.0
9	35	173	77	28	25.3
10	30	180	80	48	31.9

\*Skinfold is sum of triceps, subscapular and suprailliac skinfold.

% Body Fat calculated as described in reference (5).



TABLE 2. MK-15 CANISTER DURATION STUDY. DATA TAKEN AT 65 FSW WITH A WATER TEMPERATURE OF 12.9°C.

Test Number	Diver Number	CANISTER WEIGHT (kg)		(l/min) Overall	OXYGEN CONSUMPTION (l/min)		CANISTER DURATION (minutes)	
		Pre-Dive	Post-Dive		Exercise	Rest	0.5%	1.0%
1	1	4.253	4.258	1.03	2.2	.62	310	538
2	2	4.240	4.992	1.06	2.4	.66	304	359
3	3/8	4.355	5.274	1.06	2.4	.79	332	360
4	5/10	4.275	4.923	.80	2.1	.58	300	363
5	7	4.231	4.886	.80	2.1	.55	360	420
<hr/>								
Mean		4.273	4.867	.95	2.24	.64	321	368
Standard Deviation		±.049	0.373	±.14	±.15	±.09	±25	±31

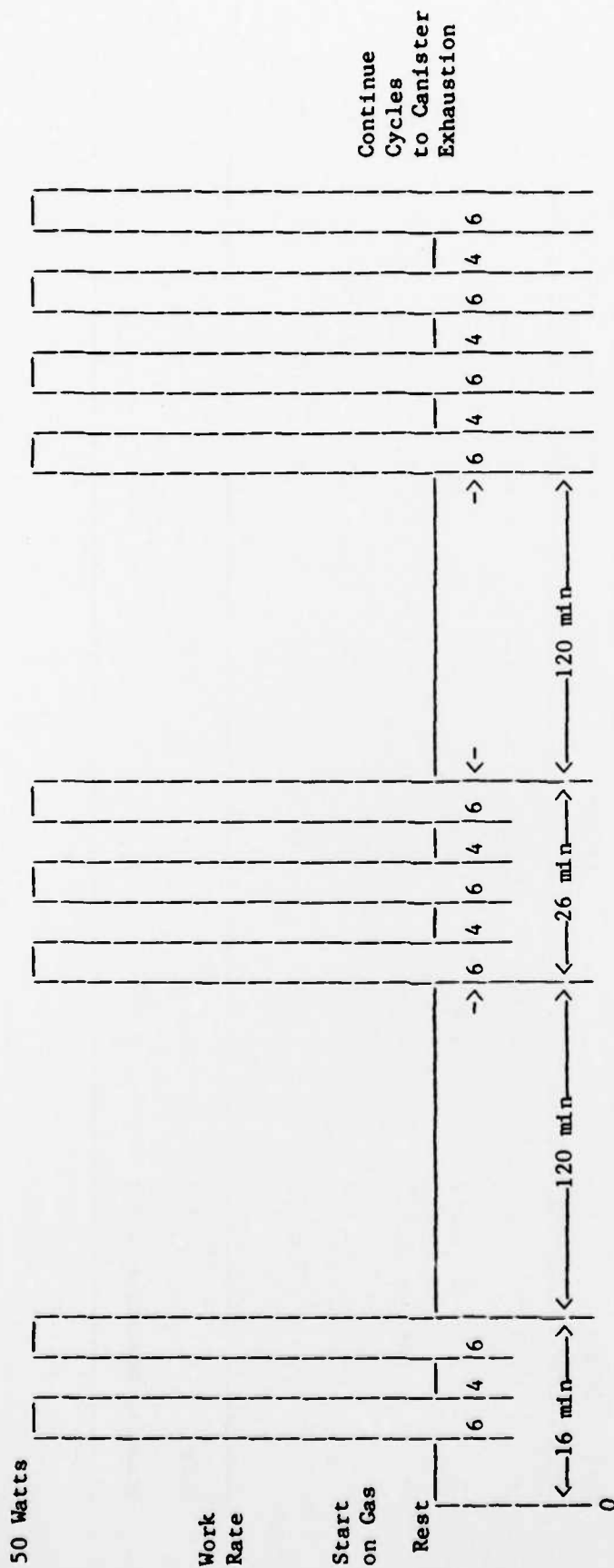
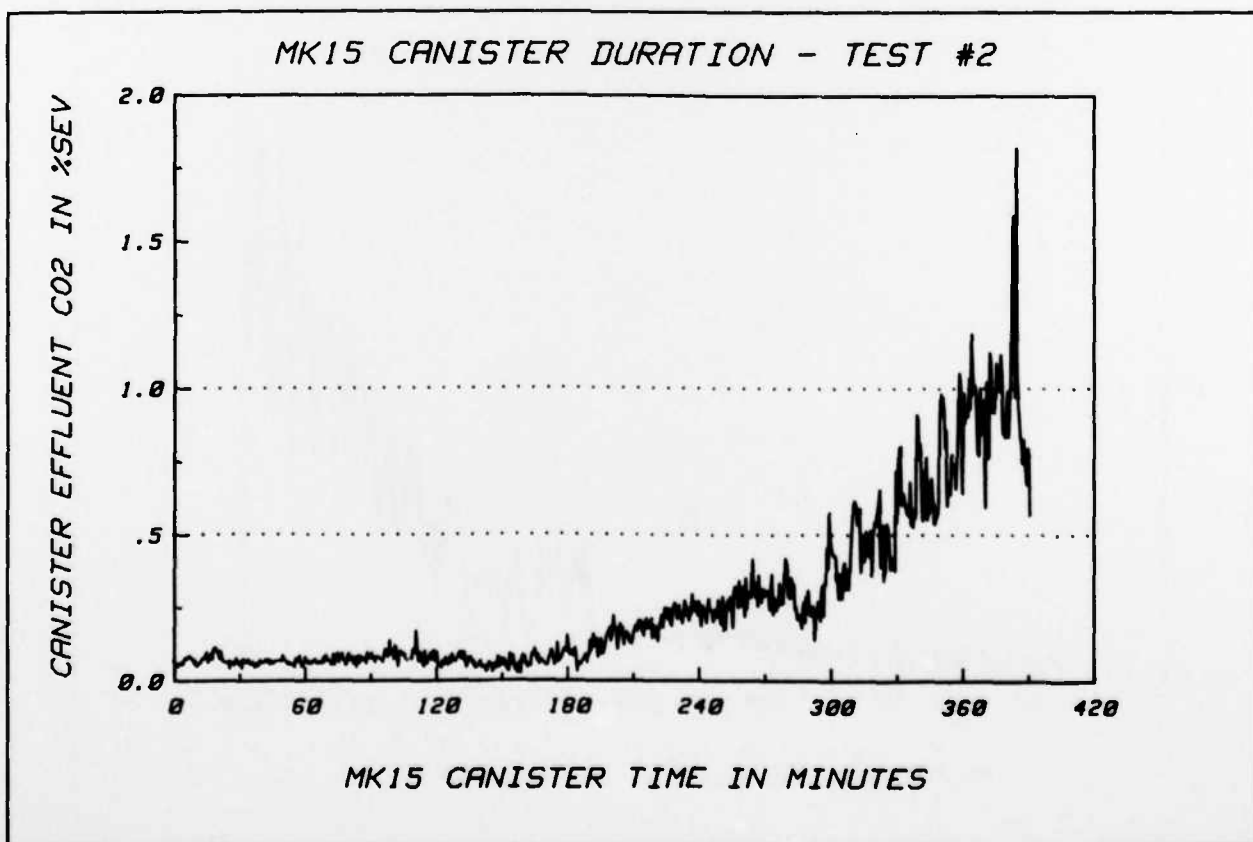
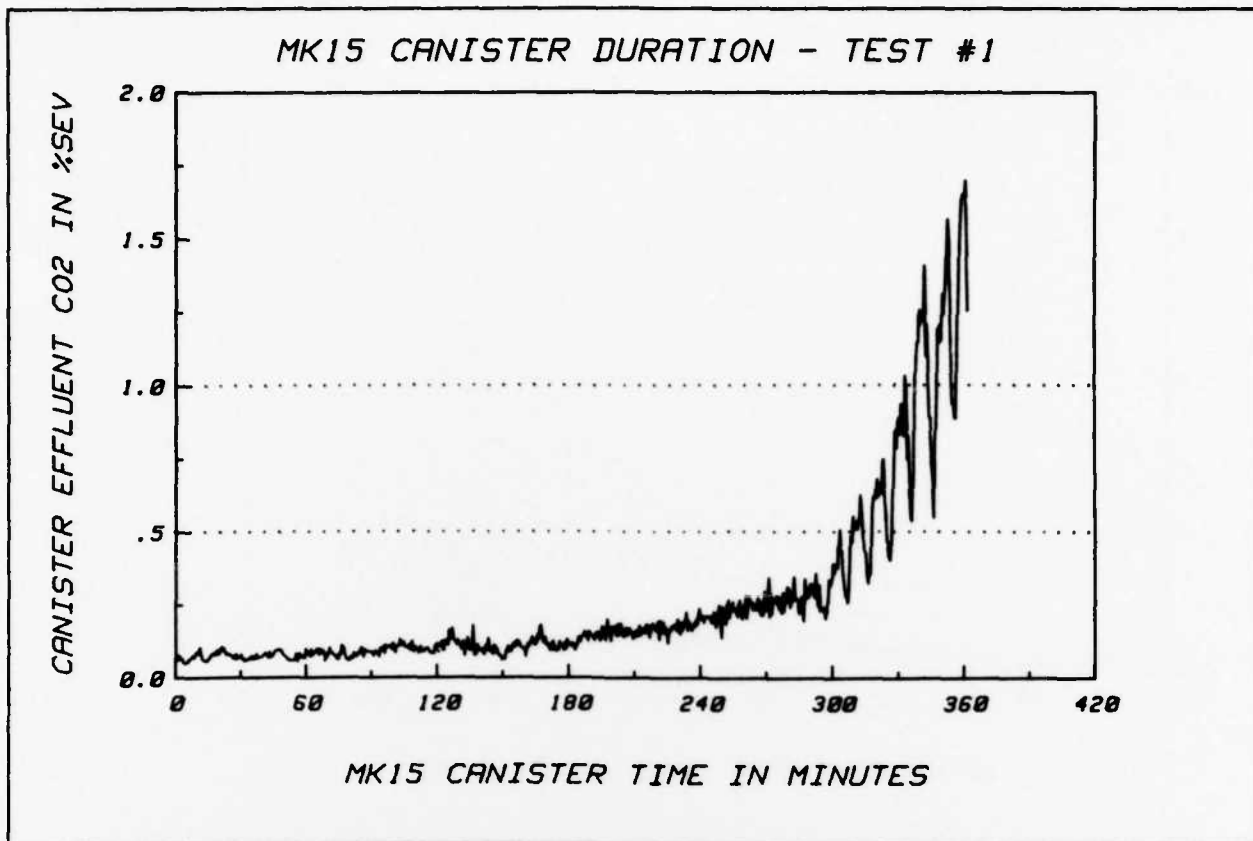
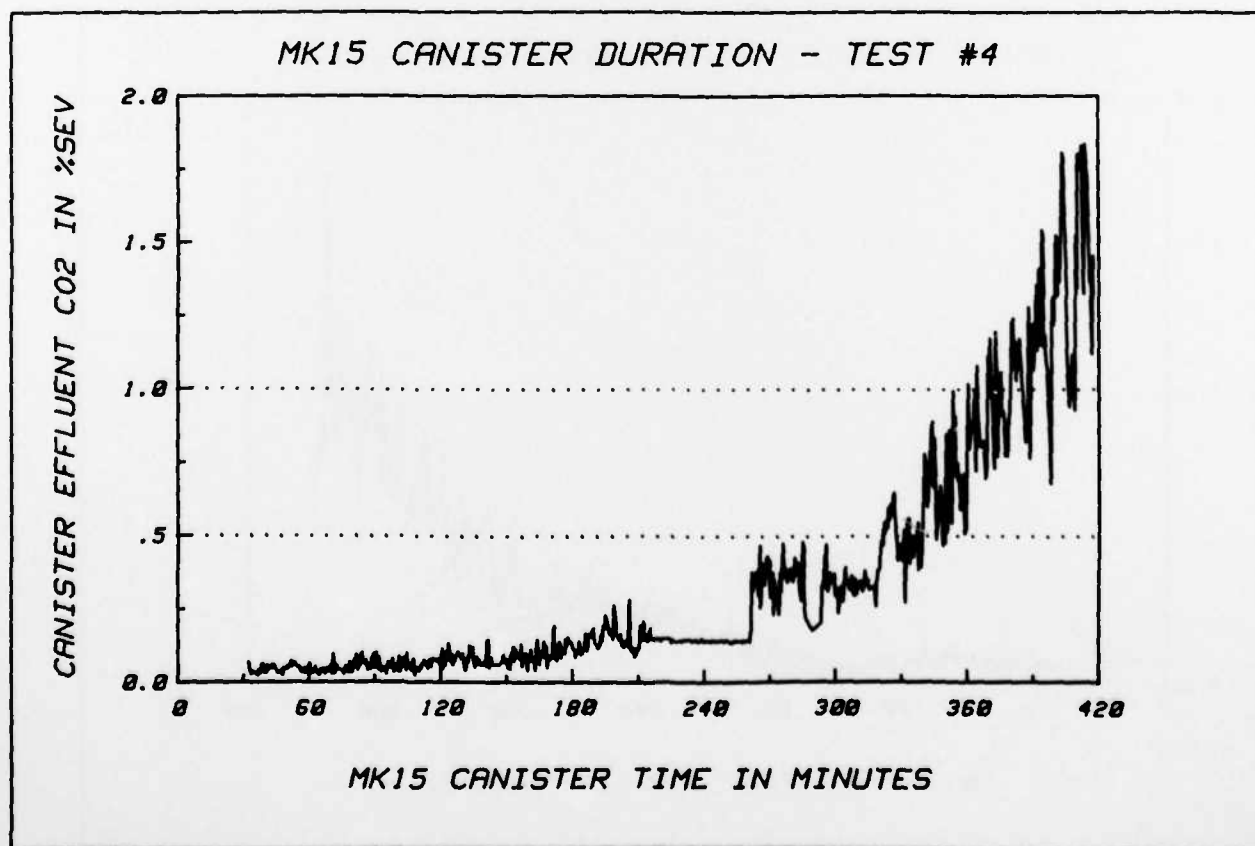
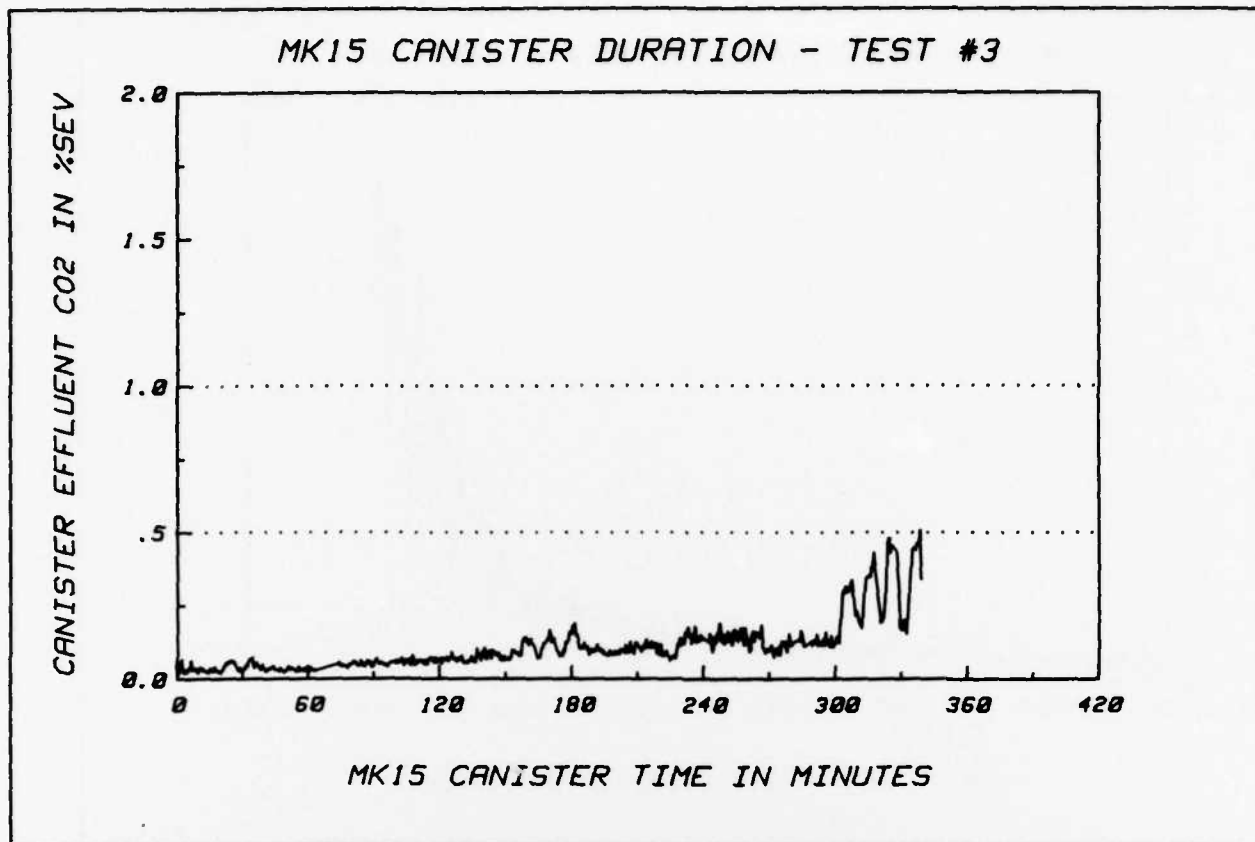


Figure 1. Resting Canister Duration Protocol



FIGURES 2A, 2B. Canister Effluent CO<sub>2</sub> Versus Time for Tests 1 and 2.



FIGURES 2C, 2D. Canister Effluent CO<sub>2</sub> Versus Time for Test 3 and 4.  
Data representation for Test 3 is incomplete.

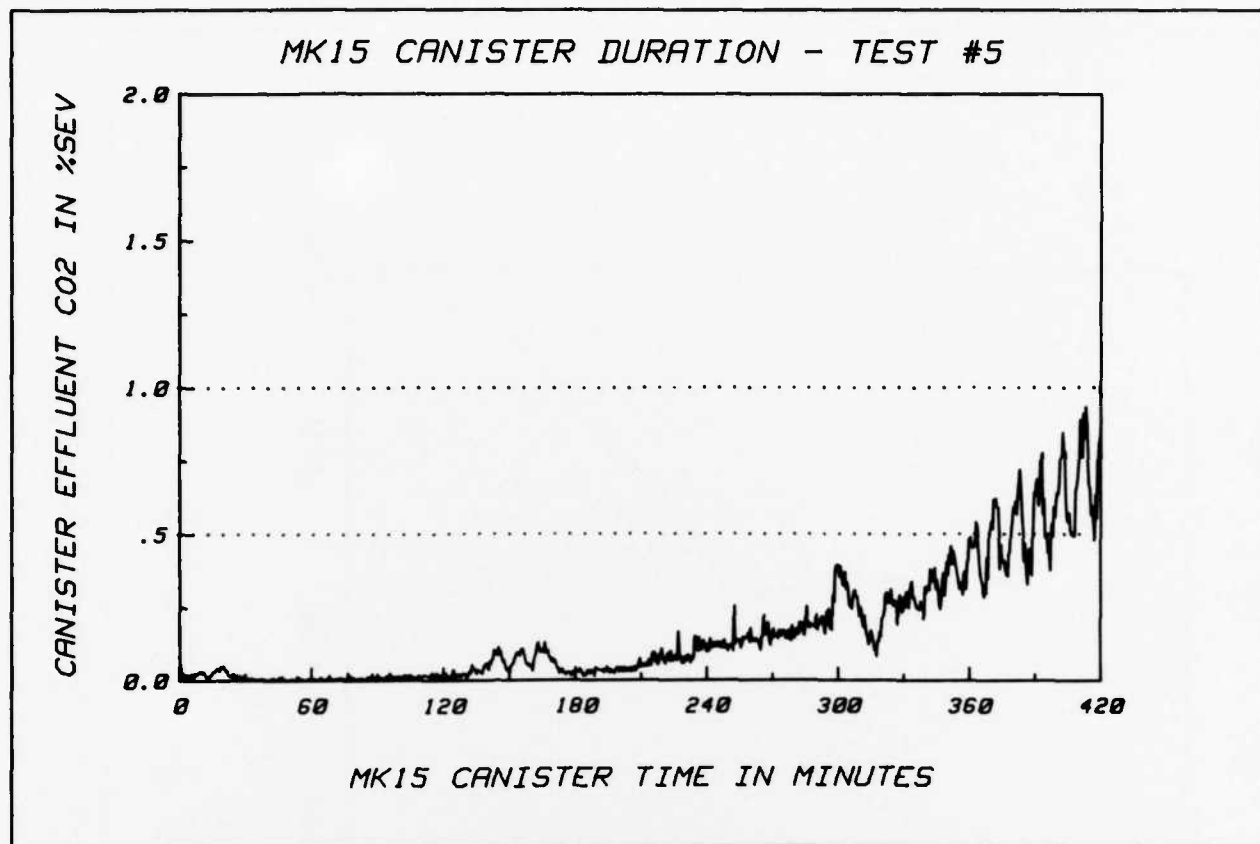
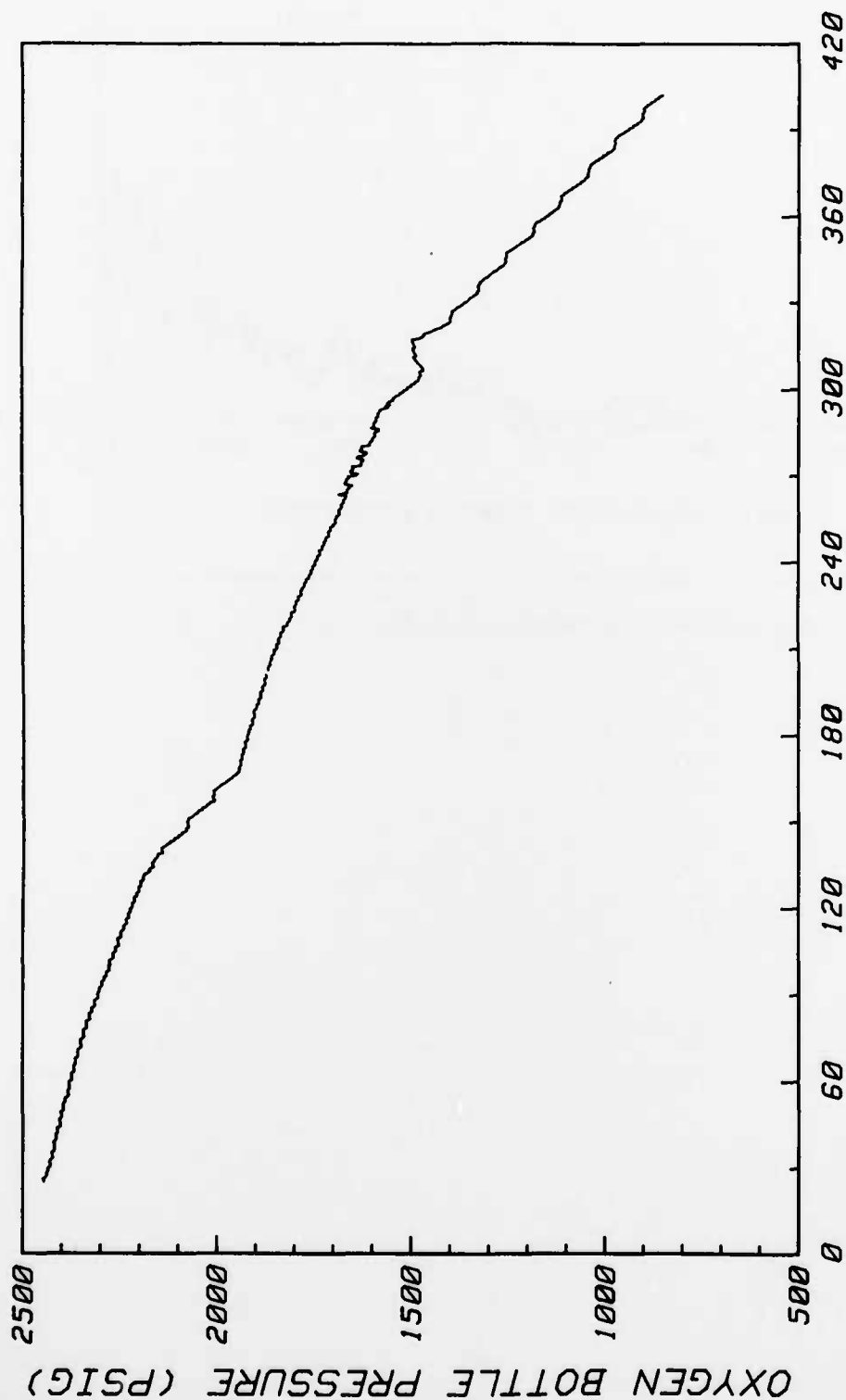


FIGURE 2E. Canister Effluent CO<sub>2</sub> Versus Time for Test 5.

# MK15 CANISTER DURATION - TEST #5



MK15 CANISTER TIME IN MINUTES

FIGURE 3. Typical oxygen bottle pressure decline over the entire period of one study. The long straight line declines in bottle pressure represent periods of rest while the more jagged areas represent the 6 minute work periods.

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